PhD student: Emanuele Carella

Cooperative, Connected and Automated Mobility: Congestion-Aware CACC Accelerated Control On Mesoscopic Traffic Model

Tutor: Stefania Santini

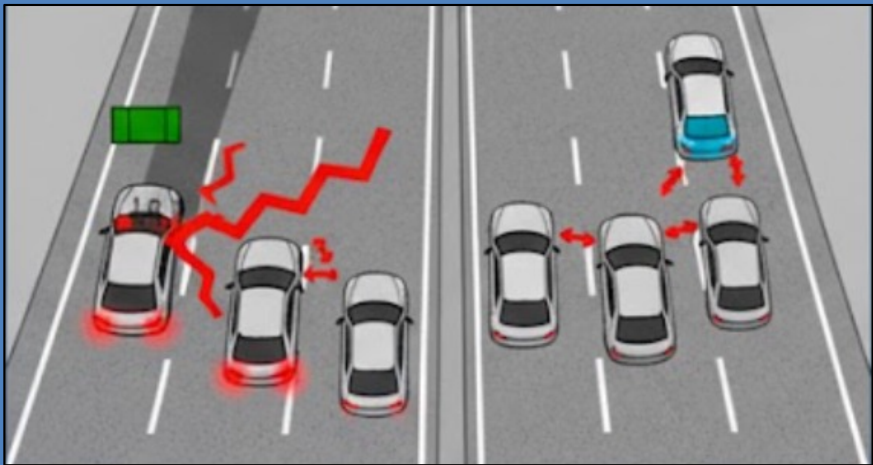
Cycle: XXXIX Year: Second

My background

- **Master Degree** Mechatronics Engineering from Politecnico Di Torino
- **Master Thesis:** Analysis of the context of a rally competition for the modelling of a hybridized vehicle (In collaboration with Panda 4WD-H PoliTO)
- **Research Group:** DAiSY Lab (Prof. Stefania Santini)
- **PhD start date:** November 2023
- **Scholarship type: No Scholarship**

Research Field: CCAM 1/2

The Challenge: Limitations of Current Adaptive Cruise Control (ACC)



Limitation of Current Adaptive Cruise Control (ACC):

- **Shockwave phenomena** : standard ACC struggles with sudden traffic fluctuation, leading to abrupt braking.
- **Phantom Traffic Jams**: In traffic with high ACC penetration, vehicles are susceptible to self-organized ''phantom'' traffic jams

The Promise : Cooperative-Adaptive Cruise Control (CACC)

- CACC leverages **Vehicle-to-Everything (V2X) communication,** allowing vehicles to share real-time information.
- **Enhances Control:** by combining shared data with local sensor information, CACC optimizes longitudinal control.

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Research Field: CCAM 2/2

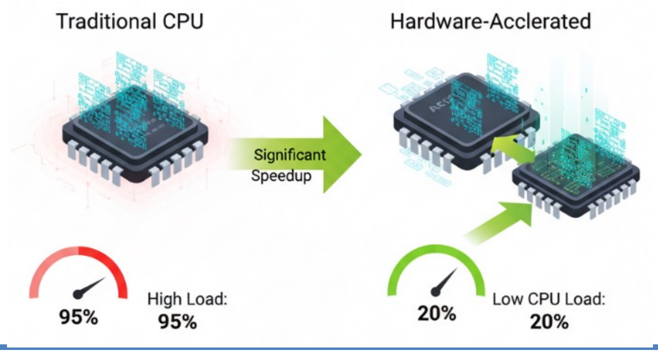
The Challenge: Implementing High-Performance CACC

Computational Burden of CACC with Model Predictive Control

- MPC is an effective solutions for implementing precise control for CACC, since it generates control actions under system constraints perfectly complaint with multi-vehicle interactions, safety issue, comfort and efficiency
- It comes with a significant computational cost, that grows substantially with the number of vehicles, prediction horizon, and system nonlinearities.

My Research Focus: A two-pronged Approach

Hardware-Accelerated Control Framework for make the computational loads lighter:



Embedding Traffic Awareness for enabling individual vehicles to recognize and react to traffic disturbances

My Second Year: Study & Training activities

The focus of my second-year activity consists in capturing all the implementations of MPC control algorithm on standard embedded platform and how to exploit acceleration hardware like FPGA to make it faster. In particular, the control algorithms are deconstructed and redesigned to create a hybrid architecture (Processor + FPGA) assigning which part is suitable to be run on the processor or translated in hardware code (vhdl)

For this reason, I attended to various seminars and courses, the most relevant of which are listed below:

- *Courses*
  - *'Embedded Systems"* - Professor Alessandro Cilardo
  - *"Testing and validation of automated road vehicles"* - Professor Angelo Coppola
- *Seminars:*
  - *'Safety Assessment for Autonomous vehicles: Approaches and Challenges"* – Professor Peter Popov
  - *'IEE ITSS Italian Chapter Annual Meeting and PhD Award 2025"* – IEE ITSS Italian Chapter

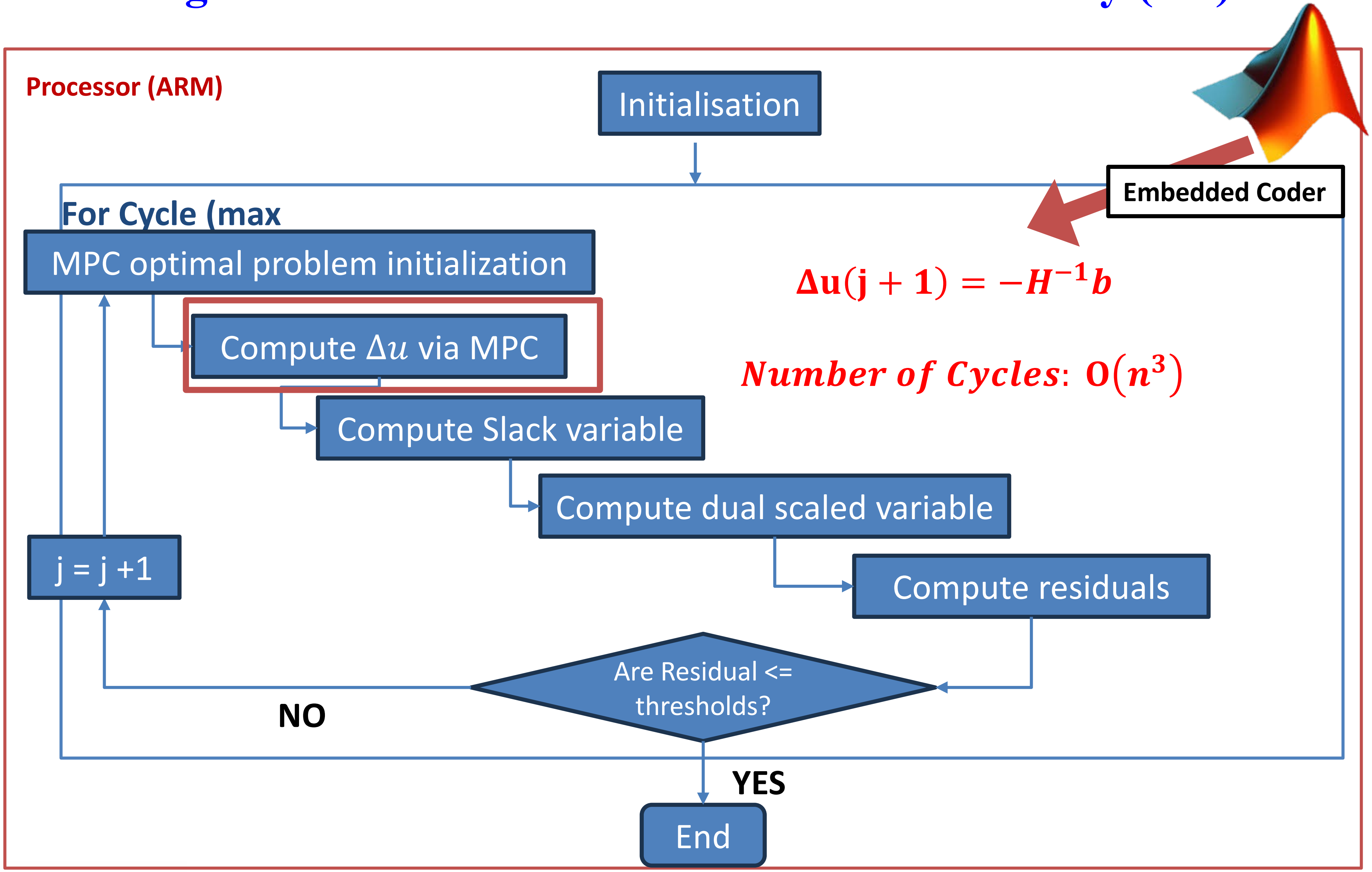
Articles:

- *A Survey of the Implementation of Linear Model Predictive Control on FPGAs*, Ian McInerney et al.
- *FPGA Implementation Framework for Low Latency Nonlinear Model Predictive Contro*l, Vaishali Patne et al.
- *Multi-objective Co-design for model predictive control with an FPGA,* B. Khusainov et al.

Research Activity: Problem Statement

- **Problem**
  - The CACC algorithms based on MPC have reached such a high maturity, from a control perspective, that they are ready to be implemented on actual hardware. However, the computationally complexity is so high for traditional hardware platform to compromise with approximated solution (Explicit MPC) and/with high hardware cost.
- **Objective**
  - Design and develop a control algorithm architecture that best exploits the acceleration hardware feature, like parallel computation
  - Evaluate and benchmark acceleration technologies (CPU, GPU, FPGA) through prototypes to determine the most efficient and feasible hardware for real-time implementation.
- **Methodology**
  - Profile and optimized MPC-based CACC algorithms to identify computational bottlenecks and apply algorithmic acceleration
  - Implementation of a test bench for simulating stressful driving scenario and acquiring profiling data

Research Activity: Algorithm reconstruction for hybrid modelling and simulation: ADMM Solver Case Study (1/2)



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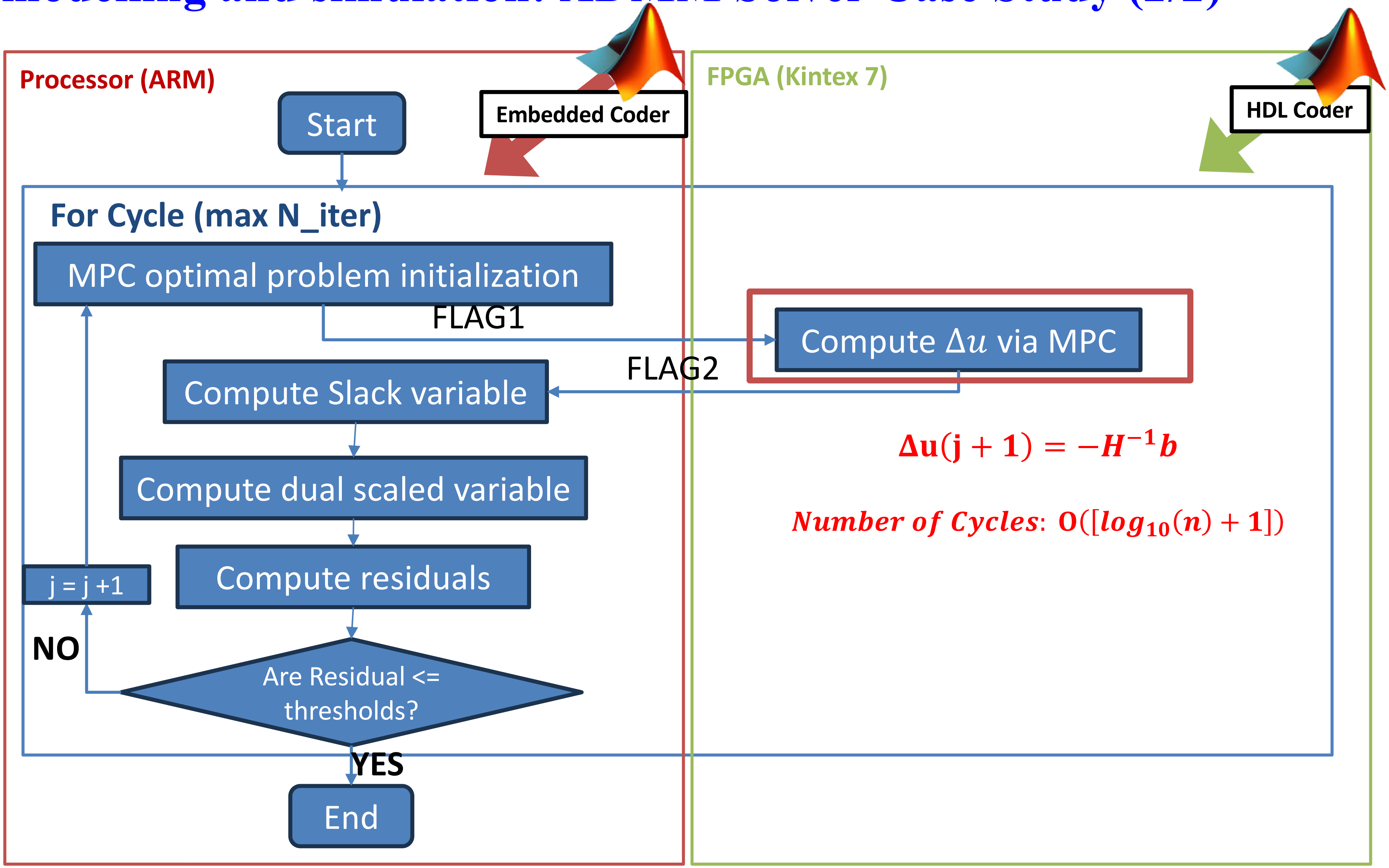
Research Activity: Algorithm reconstruction for hybrid modelling and simulation: ADMM Solver Case Study (2/2)



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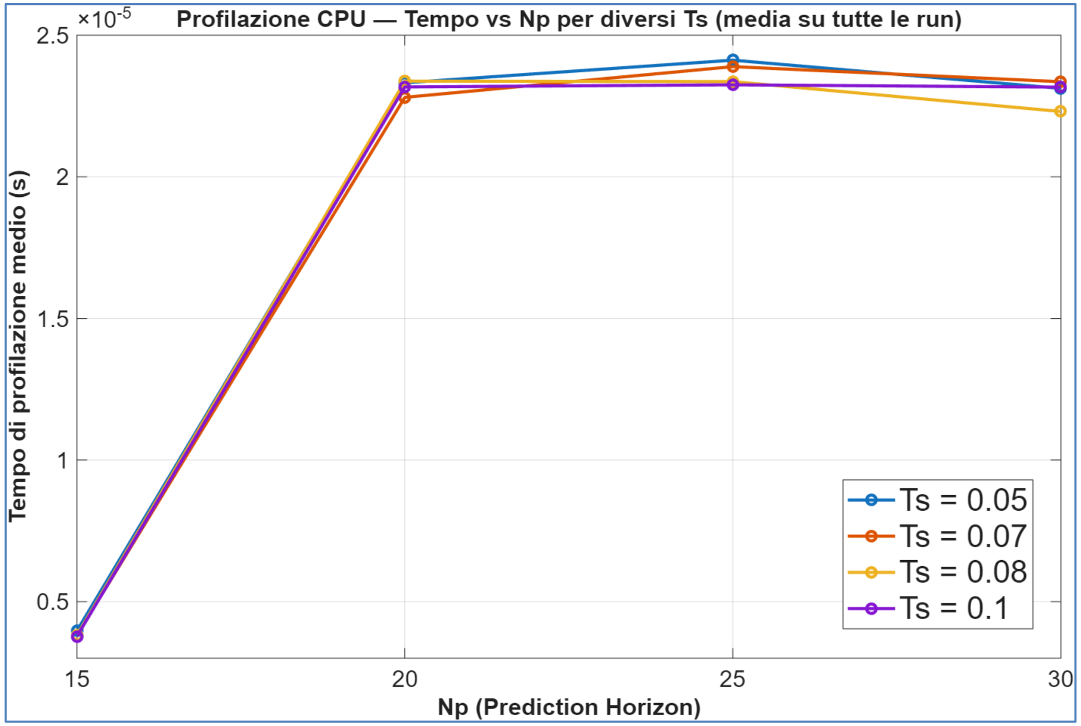
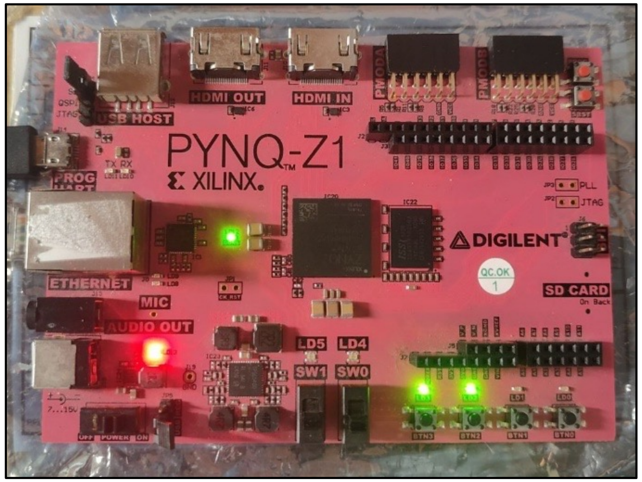
Research Activity: Testbench implementation for CACC control algorithm assessment and code profiling

Profilation data Processor Only





Study and Training Activities – Credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1	0	1.1	8.9	0	10
Bimonth 2	5	0.4	4.6	0	10
Bimonth 3	6	0.9	3.1	0	10
Bimonth 4	9	1.1	0	0	10.1
Bimonth 5	0	1	9	0	10
Bimonth 6	0	2.4	7.4	0	10
Total	20	6.9	39.9	0	
Expected	30 - 70	10 - 30	80 - 140	0 - 4.8	

Next Year

- Extension to nonlinear/adaptive MPC formulations and Scalable Cooperative Control Architectures as distributed/hierarchical multi-agent control

- Modeling and incorporation of Communication Uncertainty like communication delays, packet losses, and asynchronous updates within the control framework.

- Explore the integration of neural networks/machine learning models to complement the predictive control framework.